A PUMP

Field of the Invention

The present invention relates to pumps and to methods of operation of pumps.

Background to the Invention

Numerous mechanical devices for pumping liquids have been devised. However, mechanical pumping devices typically require moving parts to act on the liquid to be pumped. This may be undesirable in circumstances where manufacturing costs and reliability are primary concerns.

An alternative to mechanical pumping devices is disclosed in UK patent application GB 2322673. The pump of GB 2322673 includes an inlet and an outlet each having a non-return valve. Liquid is pumped between the inlet and the outlet via a pump body that includes liquid to be pumped and an amount of gas. By cyclically heating and allowing cooling of the gas within the container the volume occupied by the gas cyclically increases and decreases producing a variable force on the liquid in the pump body. As the gas is heated, liquid is pumped from the outlet through the non-return valve. On cooling liquid is drawn from the inlet through the non-return valve and into the pump body. The only moving parts required by the pump of GB 2322673 are the non-return valves.

However, the pump of GB 2322673 may not operate at high efficiency across a range of pump sizes. Furthermore, for a given pump size it may be difficult to produce sufficient pumping pressure for some applications.

It is therefore an aim of preferred embodiments of the present invention to increase pumping efficiency and/or increase pumping pressure in a pump that is substantially free from moving parts.

Summary of the Invention

According to a first aspect of the invention there is provided a pump comprising: heating means, and a pump body comprising an inlet and an outlet, the pump arrangeable in use such that the pump body includes a volume of gas and a volume of liquid, and such that heating of the volume of gas causes liquid to flow through one of the inlet and the outlet and cooling of the volume of gas causes liquid to flow through the other of the inlet and the outlet, wherein the heating means is arranged with the pump body and the pump body is shaped such that heating of the volume of gas by the heating means promotes substantially non-divergent body movement of the volume of gas.

In this way the volume of gas can move efficiently and in bulk within the pump body to enable a cooler portion of the volume of gas to come into contact with the heating means, thereby promoting more effective heating of the volume of gas.

Suitably, heating means is arranged with the pump body and the pump body is shaped such that heating of the volume of gas by the heater promotes body movement of the volume of gas substantially in a single plane.

Suitably, the heating means is arranged at a lower part of the pump body.

Suitably, the pump body includes at least one baffle therein, the baffle defining a gas flow passageway between an inner wall of the pump body and the baffle. The gas flow passageway may comprise pipe work. Suitably, the gas flow passageway comprises an annular passageway. Suitably, the gas flow passageway comprises a substantially circular annular passageway. Suitably, the gas flow passageway comprises a substantially "P" or "Q" shaped passageway.

Suitably, the pump body comprises a first part arrangeable in use to include the volume of gas, and a second part arrangeable in use to include the volume of liquid, and a diaphragm arranged in use to separate the first part of the pump body from the second part of the pump body. Suitably, the first and second parts of the pump body are releasably coupleable to one another. Suitably, the diaphragm is part of the second part of the pump body.

According to a second aspect of the invention there is provided a pump comprising: heating means, cooling means and a pump body comprising an inlet and an outlet, the pump arrangeable in use such that the pump body includes a volume of gas and a volume of liquid arranged such that heating of the volume of gas by the heating means causes

liquid to flow through one of the inlet and the outlet, and cooling of the volume of gas by the cooling means causes liquid to flow through the other of the inlet and the outlet.

By including a cooling means to provide cooling in addition to cooling that may occur due to a difference between ambient temperature and the heated gas a greater temperature range can be achieved in the volume of gas. The increase in temperature range can increase efficiency, speed of operation and pumping pressure.

Suitably, the cooling means is arranged within the pump body. Suitably, the cooling means is arranged at an upper portion of the pump body. Suitably, the cooling means comprises a thermoelectric cooling means.

The cooling means may comprise a heat sink including liquid. Suitably, the cooling means comprises a heat sink including liquid that is to be pumped by the pump and/or liquid that has been pumped by the pump.

According to a third aspect of the invention there is provided a pump comprising heating means, cooling means and a pump body comprising an inlet and an outlet, the pump arrangeable in use such that the pump body includes a volume of gas and a volume of liquid, and such that the heating means heats the volume of gas to cause liquid to flow through one of the inlet and the outlet, and the cooling means cools the volume of gas to cause liquid to flow through the other of the inlet and the outlet, the heating means and cooling means being arranged such that heating of the volume of gas by the heating means and

cooling of the volume of gas by the cooling means promote substantially the same circulatory movement in the volume of gas.

It is to be understood that the cooling means provide cooling in addition to any cooling that occurs due to a difference between ambient temperature and the heated gas.

If the same circulatory movement is promoted by heating and cooling of the volume of gas, the volume of gas does not have to change its pattern of movement between heating and cooling portions of the pumping cycle. Therefore the volume of gas can move efficiently within the pump body to enable a cooler portion of the volume of gas to come quickly into contact with the heating means on heating and enable a hotter portion of the volume of gas to come quickly into contact with the cooling means on cooling. This promotes more effective heat transfer to and from the volume of gas, leading to more efficient and faster pumping operation.

Suitably, the cooling means is arranged within the pump body. Suitably, the cooling means is arranged at an upper portion of the pump body. Suitably, the cooling means comprises thermoelectric cooling means. Suitably, the cooling means may comprise a heat sink including liquid. Suitably, the cooling means comprise a heat sink including liquid that is to be pumped by the pump and/or liquid that has been pumped by the pump.

Suitably, the heating means is arranged at a lower part of the pump body.

Suitably, the heating means is arranged above and laterally offset from the cooling means. Suitably, the heating means is arranged above and laterally offset from the cooling means such that there is no overlap between them.

In one preferred embodiment, the pump body includes at least one baffle therein, the baffle defining a gas flow passageway between an inner wall of the pump body and the baffle. The gas flow passageway may comprise pipe work. Suitably, the gas flow passageway comprises an annular passageway. Suitably, the gas flow passageway comprises a substantially circular annular passageway. Suitably, the gas flow passageway comprises a substantially "P" or "Q" shaped passageway.

Suitably, the heating means and cooling means are arranged such that heating of the volume of gas by the heating means and cooling of the volume of gas by the cooling means promote substantially non-divergent body movement of the volume of gas. Suitably, the gas flow passageway comprises a rising portion having the heating means arranged therein, and a falling portion having the cooling means arranged therein.

In an alternative embodiment the pump body may define a cavity, preferably an axially symmetric cavity, and more preferably a substantially cylindrical cavity. Suitably, the heating means and cooling means are arranged such that heating of the volume of gas by the heating means and cooling of the volume of gas by the cooling means promote movement in the volume of gas in a pattern defining a substantially toroidal surface. Suitably, the heating

means may comprise an annular heating element arranged within the pump body. Suitably, the cooling means may comprise an annular cooling element disposed above and radially outward from the heating element. Alternatively, the cooling means may comprise a cooling element disposed above and radially inward from the heating element.

According to a fourth aspect of the invention there is provided a method of operating a pump comprising heating means, and a pump body comprising an inlet and an outlet, arrangeable in use such that the pump body includes a volume of gas and a volume of liquid, the method comprising the step of: (a) heating the volume of gas with the heating means to cause liquid to flow through one of the inlet and the outlet and to promote substantially non-divergent body movement of the volume of gas within the pump body.

According to the fifth aspect of the invention there is provided a method of operating a pump comprising heating means, cooling means and a pump body comprising an inlet and an outlet, the pump arrangeable in use such that the pump body includes a volume of gas and a volume of liquid, the method comprising the steps of: (a) heating the volume of gas with the heating means to cause liquid to flow through one of the inlet and outlet; and (b) cooling the volume of gas to cause liquid to flow through the other of the inlet and the outlet.

According to the sixth aspect of the invention there is provided a method of operating a pump comprising heating means, cooling means and a pump body comprising an inlet and an outlet, the pump arrangeable in use such that the

pump body includes a volume of gas and a volume of liquid, the method comprising steps of: (a) heating the volume of gas with the heating means to cause liquid to flow through one of the inlet and outlet and promote a circulatory movement in the volume of gas; and (b) cooling the volume of gas with the cooling means to cause liquid to flow through the other of the inlet and the outlet and promote substantially the same circulatory movement as in step (a).

Brief Introduction to the Drawings

For a better understanding of the invention, and to show how embodiments of the same may be carried into effect, reference will now be made, by way of example, to the accompanying diagrammatic drawings in which:

Figure 1 shows a side sectional view of a pump according to a first preferred embodiment of the present invention;

Figure 2 shows a plan view of the pump of Figure 1 about the section A-A of Figure 1;

Figure 3 shows a side sectional view of a pump according to a second preferred embodiment of the present invention;

Figure 4 shows a plan view of the pump of Figure 3 about the section A-A of Figure 3;

Figure 5 shows a side sectional view of a pump according to a third preferred embodiment of the present invention;

Figure 6 shows a side sectional view of a pump according to a fourth preferred embodiment of the present invention; and

Figure 7 shows a side sectional view of a pump according to a fifth preferred embodiment of the present invention.

Description of Preferred Embodiments

Figure 1 shows a side sectional view of a pump 1 comprising a substantially cylindrical pump body 10, an inlet 12, an outlet 14 heating means in the form of a heating element 11, and cooling means in the form of a cooling element 13. The inlet 12 and outlet 14 are coupled to non-return valves 16 arranged to allow liquid to be drawn through the inlet 12 and into the pump body 10 and to allow liquid to be drawn through the outlet 14 and from the pump body 10. The pump body contains therein a body of liquid 20 and a body of gas 22.

An increase in the temperature of the body of gas 22 causes expansion and an increase in pressure within the pump body 10. The gas 22 acts on the surface of the body of liquid 20, causing liquid to be pumped from the pump body 10 through the outlet 14. The temperature of the body of gas 22 can be increased by supplying electricity to the heating element 11.

A decrease in the temperature of the body of gas 22 causes contraction and a decrease in pressure within the pump body. The gas 22 acts on the surface of the body of liquid 20, causing liquid to be drawn into the pump body

10 through the inlet 12. The temperature of the body of gas 22 can be reduced by supplying electricity to the cooling element 13, which comprises a thermoelectric device that operates as a heat pump using the Peltier effect. The cooling element 13 is provided at an upper surface of the pump body 10 to allow cooled gas to fall away under gravity, to be replaced by relatively warmer gas to be cooled.

By cyclically controlling the flow of electricity to the heating and cooling elements 11, 13 the temperature of the gas 22 can be controlled, allowing the pump 1 to deliver a desired average flow rate of liquid 20. The inclusion of the cooling element 13 to provide cooling in addition to any cooling that may occur due to a difference between ambient temperature and the heated gas 22 allows a greater temperature range to be achieved in the volume of gas 22. The increase in temperature range can decrease the length of pumping cycles, thereby increasing speed of operation of the pump, or smoothing the output profile by allowing a greater number of shorter pumping cycles to be used to provide a desired flow rate. The increase in temperature range can also increase the pumping pressure possible for a particular pump body.

By including pressure and temperature sensors 15 into the pump body 10 a feedback control system can be envisaged to monitor and accurately control the average flow rate of liquid 20. Using feedback control can account for changes in ambient conditions that may affect the rate of heat loss from the pump body 10. Also, a pressure sensor can be arranged to detect an over pressure condition that is indicative of a blockage or partial blockage somewhere in the liquid path. Accurate control of the flow rate

coupled with simple blockage detection is of particular importance in some applications, for example medical applications. Furthermore, in the event of a blockage occurring and then becoming freed the maximum amount of liquid that the pump 1 will deliver is the same as would be delivered in a normal pumping cycle.

Figure 2 shows a plan view of the pump 1 of Figure 1 along section A-A in the direction of the section arrows.

Figure 3 shows a side sectional view of a pump 2 comprising a substantially cylindrical pump body 10 similar to that shown in Figures 1 and 2, with like reference numerals used to denote like elements. As the gas 22 within the pump body 10 is heated by the heating element 11 it tends to rise by convection, as shown by arrows 23. The rising gas 22 circulates out from the area above the heating element 11 and causes cooler gas 22 to descend in the region within the pump body 10 adjacent to the wall 18, as shown by arrows 24.

The temperature of the body of gas 22 can be reduced by supplying electricity to the cooling element 13, which comprises a thermoelectric device that operates as a heat pump using the Peltier effect. The cooling element 13 is provided at an upper surface of the pump body 10 to allow cooled gas to fall away under gravity, to be replaced by relatively warmer gas to be cooled. To enable the gas 22 to move in substantially the same circulatory movement on heating and cooling the cooling element is provided as a ring. The ring is of grater internal diameter than the diameter of the flat circular coil which makes up the heating element 11. In this way the heating means and

cooling means promote movement in the volume of gas 22 in a pattern defining a substantially toroidal surface.

As the same circulatory movement is promoted by heating and cooling of the volume of gas 22, the volume of gas does not have to change its pattern of movement between heating and cooling portions of the pumping cycle. Therefore the volume of gas can move efficiently within the pump body to enable a cooler portion of the volume of gas to come quickly into contact with the heating means on heating and enable a hotter portion of the volume of gas to come quickly into contact with the cooling means on cooling. This promotes more effective heat transfer to and from the volume of gas 22, leading to more efficient and faster pumping operation.

Figure 4 shows a plan view of the pump 2 of Figure 3 along section A-A in the direction of the section arrows. The arrows 23 appear as dots and the arrows 24 appear as crosses to illustrate the direction of gas circulation at the cross section.

Figure 5 shows a side sectional view of a pump 3 according to a third preferred embodiment of the present invention. The pump 3 is similar to those shown in Figures 3 and 4 in operation; however the pump body 10 is substantially spherical. The heating element 11 is arranged within a lower portion of the pump body 10 and comprises a substantially flat circular coil. The cooling element 13 is arranged in a ring between substantially latitudinal lines toward an upper part of the pump body 10. As with the pump of Figure 3 and 4, the heating means and cooling

means promote movement in the volume of gas 22 in a pattern defining a substantially toroidal surface.

Figure 6 shows a side sectional view of a pump 4 according to a fourth preferred embodiment of the present invention. The pump body 10 defines a closed annular gas flow passageway made up of pipe sections of substantially circular cross section. The gas flow passageway is arranged in "P" shape. The heating element 11 is arranged such that heating of the volume of gas 22 promotes substantially non-divergent body movement of the volume of gas 22. The left part of the pump body 10 as shown comprises a rising portion and includes the heating element 13 at a lower portion. The right part of the pump body 10 as shown comprises a falling portion. As the gas 22 within the pump body 10 is heated by the heating element 11 it tends to rise by convection, as shown by arrows 23. The rising gas 22 circulates from the rising portion to the falling portion, where it falls as shown by arrows 24.

Figure 7 shows a side sectional view of a pump 5 according to a fifth preferred embodiment of the present invention. The pump body 10 defines a closed annular gas flow passageway made up of pipe sections of substantially circular cross section. The gas flow passageway is arranged in "Q" shape. The heating element 11 is arranged such that heating of the volume of gas 22 promotes substantially non-divergent body movement of the volume of gas 22. The left part of the pump body 10 as shown comprises a rising portion and includes the heating element 13 at a lower portion. The right part of the pump body 10 as shown comprises a falling portion. As the gas

22 within the pump body 10 is heated by the heating element 11 it tends to rise by convection, as shown by arrows 23. The rising gas 22 circulates from the rising portion to the falling portion, where it falls as shown by arrows 24. The gas in the falling portion is cooled by the cooling element 13, and this promotes both body movement of the gas 22 and movement of the gas 22 in a constant circulatory direction.

Each of the embodiments show in the accompanying Figures comprises a pump body 10 formed in two parts. The two parts of the pump body shown comprise a first part 10A that when in use includes the volume of gas, and a second part 10B that when in use includes the volume of liquid. The first and second parts 10A, 10B are coupled to one another so that neither gas nor liquid can escape between them.

In some pumping applications, for example in medical pumps for drug delivery, it is desireable that the liquid being pumped is separated from the rest of the pump body to avoid cross contamination when the pump is reused. A diaphragm can be provided as a part of the first or second part 10A, 10B of the pump body to isolate the liquid being pumped from the volume of gas within the pump body. In medical pumps the part of the pump that does come into contact with the liquid being pumped is often intended for a single use, and is referred to as a 'giving set'. In particularly preferred embodiments the first and second parts 10A, 10B of the pump body are releaseably coupled to one another to provide a giving set comprising the second part 10B valves 16 and a diaphragm coupled to the second part 10B of the pump body.

A flexible diagram of a plastics material, for example polythene can be used, and is preferably arranged so that the diaphragm can move in response to pressure changes in the volume of gas without undergoing plastic deformation in normal use of the pump. In the accompanying Figures a diaphragm can be arranged across the upper surface of the liquid 20 in the second part 10B of the pump body.

Two further embodiments of the pump will now be described. The first further example embodiment is based on pump shown in Figures 1-4, but comprises a heating element which is semicircular when viewed in play. The second further embodiment along similar lines can be formed by dividing the pump body (10) of the pump (3) shown in Figure 5 in half along a vertical axis.

In both these additional embodiments the provision of heating on only one side of the lower portion of the pump body causes a non-divergent body movement within the volume of gas contained inside the pump body. The non-divergent flow promoted by this arrangement reduces the likelihood of chaotic flow/large scale turbulence occurring in the volume of gas in the pump body. Turbulent flow in the volume of gas in the pump body has been found to result in less efficient heat transfer, so maintaining non-divergent flow enables a higher heat transfer rate to be achieved without reducing efficiency.

In any of the above embodiments comprising a cooling means, the cooling means may comprise a heat sink including liquid. For example, a tube arranged to carry liquid therethrough may be provided in addition to or as

an alternative to a thermoelectric cooling device. The liquid provided to the cooling means may have been cooled using a fluid based refrigeration cycle, or by other means. In a preferred embodiment the cooling means comprises a heat sink in contact with an external surface of the pump body and is arranged to receive liquid that has been pumped by the pump.
This allows the liquid from the pump to be warmed prior to final delivery, which may be advantageous in certain applications, e.g. medical applications.

An improved pump has been described that offers advantages in terms of efficiency over similar existing pumps, without compromising in the simplicity of the pumping scheme.

Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same,

equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.